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Constructivism and Science Education: A Further Appraisal

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This paper is critical of constructivism. It examines the philosophical underpinnings of the theory, it outlines the impact of the doctrine on contemporary science education, it details the relativist and subjectivist interpretation of Thomas Kuhn's work found in constructivist writings, it indicates the problems that constructivist theory places in the way of teaching the content of science, and finally it suggests that a lot of old-fashioned, perfectly reasonable educational truisms and concepts are needlessly cloaked in constructivist jargon that inhibites communication with educationalists and policy makers.

KEY WORDS: constructivism; epistemology; Thomas Kuhn.

INTRODUCTION

A decade ago Peter Fensham correctly claimed that "The most conspicuous psychological influence on curriculum thinking in science since 1980 has been the constructivist view of learning" (Fensham, 1992, p. 801). To this psychological influence has been added a strong dose of Kuhnian-inspired philosophical constructivism. Contemporary educational constructivism is a heady mixture of the supposedly psychological thesis that "children must construct their own knowledge" and the supposedly Kuhnian epistemological thesis that "all knowledge is relative and paradigm dependent."

Constructivism is undoubtedly a major theoretical influence in contemporary science and mathematics education. Some would say it is *the* major influence. In its postmodernist and deconstructionist form, it is a significant influence in literary, artistic, history, and religious education. Constructivism seemingly fits in with, and supports, a range of multicultural, feminist, and broadly reformist programmes in education. Although constructivism began as a theory of learning, it has progressively expanded its dominion, becoming a theory of teaching, a theory of education, a theory of the origin of ideas, and a theory of both personal knowledge and scientific knowledge. In a recent constructivist anthology Yvon Pépin goes so far as to claim that constructivism, "also offers a global perspective on the meaning of the human adventure, on the way human beings impart meaning to their whole existence in order to survive and adapt" (Pépin, 1998, p. 174). Constructivism has become education's version of the "grand unified theory," plus a bit more.

High hopes are held for constructivism, with two proponents in science education saying that it "can serve as an alternative to the hunches, guesses, and folklore that have guided our profession for over 100 years" (Mintzes and Wandersee, 1998, p. 30). The introductory essay of a recent constructivist anthology announces that, "'critical-constructivism' stands in opposition to the unmitigated sociopolitical vaporousness only too frequently encounted nowadays" (Larochelle and Bednarz, 1998, p. 20). Another leading advocate has, understatedly, said, "If the theory of knowing that constructivism builds upon were adopted as a working hypothesis, it could bring about some rather profound changes in the general practice of education" (Glasersfeld, 1989, p. 135).

Constructivist influence has extended beyond just the research and scholarly community: it has had an impact on a number of national curricular documents and national education statements. Speaking of recent U.S. science and mathematics education reforms, Catherine Twomey Fosnot has commented

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that "Most recent reforms advocated by national professional groups are based on constructivism. For example the National Council for Teachers of Mathematics . . . and . . . the National Science Teachers Association" (Fosnot, 1996, p. x). The U.S. National Science Teachers Association Standards for Teacher Preparation—standards according to which the value of institutions' teacher education programmes are to be evaluated—is replete with constructivist claims.

The debate over constructivism in education is a local occurrence of the more general "Science Wars" that have been raging in the final decades of the twentieth-century.[2] One proponent has written:

> I have a candidate for *the* most dangerous contemporary intellectual tendency, it is . . . constructivism. Constructivism is a combination of two Kantian ideas with twentieth-century relativism. The two Kantian ideas are, first, that we make the known world by imposing concepts, and, second, that the independent world is (at most) a mere "thing-in-itself" forever beyond our ken. . . . [considering] its role in France, in the social sciences, in literature departments, and in some largely well-meaning, but confused, political movements [it] has led to a veritable epidemic of "worldmaking." Constructivism attacks the immune system that saves us from silliness. (Devitt, 1991, p. ix)

Constructivism influenced the recently released U.S. National Science Education Standards (NRC, 1996). The 1992 *Draft Standards* recognised that the history, philosophy, and sociology of science ought to contribute to the formation of the science curriculum. But when the contribution of philosophy of science was, in an Appendix, elaborated, it turned out to be *constructivist* philosophy of science. After dismissing a caricature of logical empiricism, the document endorses "A more contemporary approach, often called postmodernism [which] questions the objectivity of observation and the truth of scientific knowledge." It proceeds to state that "science is a mental representation constructed by the individual," and concludes, in case there has been any doubt, that "The National Science Education Standards are based on the postmodernist view of the nature of science." Not surprisingly these endorsements caused some scientific and philosophical eyebrows to be raised, and a battle to be joined over whose "Nature of Science" was going to be mandated for U.S. students.[3]

The revised 1994 *Draft* emerged *sans* the Appendix, but its constructivist content was not rejected, merely relocated (NRC 1994). Learning science was still identified with "constructing personal meaning." And the history of science was seen in distorted-Kuhnian terms as the "changing commitments of scientists [which] forge change commonly referred to as advances in science." As one commentator, sympathetic to constructivism, remarked:

> even though the term *constructivism* is not used even once in the NSES, it is clear that individual constructivism . . . is the driving theory of teaching and learning throughout the document . . . the theoretical underpinning of the document is made to be invisible. (Rodriguez, 1998, p. 30)

And constructivist influence is not just confined to the U.S. The New Zealand National Science Curriculum is heavily influenced by constructivist theories and ideals (Matthews, 1995). Comparable documents in Spain, the UK, Israel, Australia, and Canada bear, to varying degrees, the imprint of constructivist theory. In the past few years a number of significant anthologies have been devoted to explicating constructivist principles and delineating constructivist practice (Larochelle *et al*., 1998; Mintzes *et al*., 1998; Steffe, 1994).

The Editorial Introduction to a special issue of the *Journal of Teacher Education* devoted to constructivism, nicely sums up the place of constructivism in the contemporary educational landscape:

> Constructivism is the new rallying theme in education. Its popularity derives from its origins in a variety of disciplines, notably philosophy of science, psychology, and sociology. The implications of a constructivist perspective for education differ depending on its disciplinary foundation, but professional education groups as diverse as the National Association for the Education of Young Children and the National Council of Teachers of Mathematics have based revisions of their standards for practice on the constructivist assumption that learners do not passively absorb knowledge but rather construct it from their own experiences. (Ashton, 1992, p. 322)

But constructivism has not been without its critics. Among the more detailed and scholarly have been

[2]For contributions to the "Science Wars," see Passmore (1978), Holton (1993), Gross and Levitt (1994), Ross (1996), Gross *et al.* (1996), Sokal and Bricmont (1998), and Koertge (1998).

[3]Gerald Holton has documented efforts made to counteract constructivist interpretations of the history and philosophy of science in the *Standards* (Holton, 1996). See also contributions to Stotsky (2000).

Suchting (1992), Phillips (1995, 1997), Nola (1997), Osborne (1996), Kelly (1997), Slezak (2000), McCarty and Schwandt (2000), and McCarthy and Sears, (2000). In recent years there have been three major publications that have attempted a wide-ranging appraisal of constructivism: the National Society for the Study of Education *99th Yearbook* (Phillips, 2000); the anthology *Constructivism and Science Education: A Philosophical Examination* (Matthews, 1998); and a special issue of *Science and Education* devoted to the subject (Volume 9, Number 6, 2000). Ten years ago, in the pages of this journal, I published a review of the epistemological critiques of constructivism (Matthews, 1993). Given the scope of the doctrine and its continuing influence, it is time to once again examine its epistemological, psychological, and pedagogical claims.

THE SCOPE OF CONSTRUCTIVISM

Constructivism is far more than a theory of learning. The range of constructivist concerns can be seen in the subheadings of a science education article, where we are informed of, "A constructivist view of learning," "A constructivist view of teaching," "A view of science," "Aims of science education," "A constructivist view of curriculum," and "A constructivist view of curriculum development" (Bell, 1991). The expanded purview of constructivism is also apparent in the remarks of another constructivist that, "this approach [constructivism] holds promise for the pursuit of educational objectives other than those associated exclusively with cognitive development . . . the constructivist point of view makes it possible to develop a vision of the whole educational phenomena which is comprehensive and penetrating" (Pépin, 1998, p. 173). Another author writes, "Constructivism is a postmodern theory of knowledge with the potential to transform educational theory" (Fleury, 1998, p. 156). It is not surprising then that, "For several years now, across the country [USA], preservice and in-service teachers have been considering constructivism as a referent for their philosophies of education" (Bentley, 1998, p. 244). And constructivism is not just a theory about education, it is a theory about one of culture's greatest and most enduring achievements, namely science. As Bentley says, "Indeed as an epistemology, constructivism speaks to the nature of science" (Bentley, 1998, p. 243).

Constructivism spreads to still further fields. It increasingly presents itself as an ethical and political theory, as well as a learning, a teaching, and an epistemological theory. As a recent paper says, "There is also a sense in which constructivism implies caring—caring for ideas, personal theories, self image, human development, professional esteem, people—it is not a take-it-or-leave-it epistemology" (Watts, 1994, p. 52). This ethical dimension is manifest in the frequency with which notions of emancipation and empowerment occur in constructivist writing. Constructivism is thought to be a morally superior position to its rivals in learning theory and pedagogy. It offers teachers "a moral imperative for deconstructing traditional objectivist conceptions of the nature of science, mathematics and knowledge, and for reconstructing their personal epistemologies, teaching practices and educative relationships with students" (Hardy and Taylor, 1997, p. 148).

There is also a political dimension to much constructivist writing. Two constructivist writers say that they are "committed to the philosophy and principles of composite grades and mixed-ability groupings" (Brass and Duke, 1994, p. 100). Another writer has identified the Progressive Education tradition as constructivist, and the British Plowden Report of the mid-1960s as the embodiment of constructivist school organisation (Hawkins, 1994).

A number of constructivists align themselves with the Critical Theory of Michael Apple, Henry Giroux, and Stanley Aronowitz. One New Zealand commentator says that "There are many parallels between the literature on the development of critical pedagogy [and] the literature on constructivist learning" (Gilbert, 1993, p. 35). This is because, "Critical theorists question the value of such concepts as individualism, efficiency, rationality and objectivity, and the forms of curriculum and pedagogy that have developed from these concepts" (Gilbert, 1993, p. 20).

For some, constructivism is even larger than a theory of learning education and science; it is almost a worldview or *weltanschuung.* One leading constructivist writes:

> To become a constructivist is to use constructivism as a referent for thoughts and actions. That is to say when thinking or acting, beliefs associated with constructivism assume a higher value than other beliefs. For a variety of reasons the process is not easy. (Tobin, 1991, p. 1)

Thus one problem posed for the appraisal of constructivism is being clear about what incarnation of

the theory is being appraised: the learning theory, theory of knowledge, pedagogical theory, theory of science, educational theory or more all-encompassing worldview.

Constructivism is clearly a "Broad Church" doctrine, and this presents problems for its appraisal. The problems are exacerbated when some constructivists simply identify constructivism with nonbehaviorist learning theory. Indeed for many writers, teachers and students this is what constructivism means. Dennis and Valentina McInerney, for instance, in their text on educational psychology say that, "We discuss the cognitive theories of Gestalt Psychology and of Bruner as examples of personal constructivism" (McInerney, 1998, p. 90). This identification is a cause of some confusion: what is a reasonable and necessary condition for constructivism (that the mind contributes something to cognition), becomes, unreasonably, both a necessary and sufficient condition. Bruner and the Gestalt theorists paid little attention to epistemology, which is the defining feature of serious constructivism. Certainly many realists in epistemology embrace nonbehaviorist learning theory: to label these people "constructivists" is to invite confusion.

Unfortunately the different dimensions of constructivism often treated as a package deal, whereby being a constructivist in learning theory is deemed to flow on to being a constructivist in all the other areas, and being a constructivist in pedagogy is deemed to imply a constructivist epistemology and educational theory. But these aspects can all be separated and each can stand alone. Thomas Kuhn, for instance, held a constructivist theory of science yet was an advocate of anticonstructivist pedagogy (Kuhn, 1959). Socrates might be seen to be a constructivist in pedagogy, yet he was an anticonstructivist in his theory of knowledge. On the other hand, Ernst Mach was a most vigorous champion of instrumentalist (constructivist?) views of science, yet was quite didactic in his pedagogy. McCarty and Schwandt rightly observe that

> There must then be something amiss in Gergen and von Glasersfeld's shared belief that objective knowledge leads necessarily to a didactic or "banking method" of teaching in which students are mental pastry shells waiting for an epistemic filling. There are no grounds to support such a claim; it is a simple non sequitur. (McCarty and Schwandt, 2000, p. 79)

Debate and analysis in science education would be more productive if the following dimensions of constructivism were separated:

1. Constructivism as a theory of learning.
2. Constructivism as a theory of teaching.
3. Constructivism as a theory of education.
4. Constructivism as a theory of cognition.
5. Constructivism as a theory of personal knowledge.
6. Constructivism as a theory of scientific knowledge.
7. Constructivism as a theory of educational ethics and politics.
8. Constructivism as a worldview.

RADICAL CONSTRUCTIVISM

Ernst von Glasersfeld has had great influence on the development of constructivist theory in mathematics and science education in the past decade. He has published well over 100 papers, book chapters and books in fields such as mathematics and science education, cybernetics, semantics and epistemology.[4] And he has been a featured speaker at a number of international science education conferences. Von Glasersfeld is an advocate of "Radical Constructivism," a position based on "the practice of psycholinguistics, cognitive psychology, and . . . the works of Jean Piaget" (Glasersfeld, 1990, p. 1). As he provides perhaps the most systematic account of the epistemological and ontological underpinnings of psychological constructivism that can be found in the educational literature, his work will be examined here in some detail. The examination intends to illustrate some philosophical problems with constructivist theory, and more generally illustrate how the history and philosophy of science can bear upon important disputes in educational theory.

Von Glasersfeld sees himself in a constructivist tradition begun in the "18th century by Giambattista Vico, the first true constructivist" and continued by "Silvio Ceccato and Jean Piaget in the more recent past" (Glasersfeld, 1987, p. 193). This tradition tends to undermine a large "part of the traditional view of the world," above all "the relation of knowledge and reality" (Glasersfeld, 1987, p. 193). Von Glasersfeld concludes his discussion of Vico with the claim that, for constructivists:

> The word "knowledge" refers to a commodity that is radically different from the objective representation of an observer-independent world which the

[4]See especially von Glasersfeld (1987, 1989, 1991, 1992, 1995).

> mainstream of the Western philosophical tradition has been looking for. Instead "knowledge" refers to conceptual structures that epistemic agents, given the range of present experience within their tradition of thought and language, consider *viable*. (Glasersfeld, 1989, p. 124)

This can be referred to as von Glasersfeld's principle, or perhaps von Glasersfeld's philosophy (VGP), as it subsumes a number of epistemological and ontological theses, among which are the following:

1. Knowledge is not about an observer-independent world.
2. Knowledge does not represent such a world; correspondence theories of knowledge are mistaken.
3. Knowledge is created by individuals in a historical and cultural context.
4. Knowledge refers to individual experience rather than to the world.
5. Knowledge is constituted by individual conceptual structures.
6. Conceptual structures constitute knowledge when individuals regard them as viable in relationship to their experience; constructivism is a form of pragmatism.
7. There is no preferred epistemic conceptual structure; constructivism is a relativist doctrine.

And finally, in a move that many idealists before him have made, von Glasersfeld proceeds from an epistemological position to an ontological one. In one place he writes that

> Radical constructivism, thus, is *radical* because it breaks with convention and develops a theory of knowledge in which knowledge does not reflect an "objective" ontological reality, but exclusively an ordering and organization of a world constituted by our experience. The radical constructivist has relinquished "metaphysical realism" once and for all. (Glasersfeld, 1987, p. 199)

And in another place, that

> the experiencing consciousness creates *structure* in the flow of its experience; and this structure is what conscious cognitive organisms experience as "reality"—and since this reality is created almost entirely without the experiencer's awareness of his or her creative activity, it comes to appear as given by an independently "existing" world. (Glasersfeld, 1984, p. 38)

This claim suggests two further constitutive theses of VGP:

8. Knowledge is the appropriate ordering of an experiential reality.
9. There is no rationally accessible, extraexperiential reality; the term "world" is shorthand for "our experience."

In his 1989 paper, von Glasersfeld quotes approvingly Ludwik Fleck and Richard Rorty. From a 1929 paper of Fleck, he repeats: "The content of our knowledge must be considered the free creation of our culture. It resembles a traditional myth" (p. 122). From Rorty's 1982 book, he repeats that the pragmatist "drops the notion of truth as correspondence with reality altogether, and says that modern science does not enable us to cope because it corresponds, it just enables us to cope" (p. 124).

Von Glasersfeld's views first made their appearance in science education literature in 1988 (Tobin *et al*., 1988). Since then his constructivist arguments have been widely adopted, though not always cited: For many science educators, the epistemological planks of radical constructivism have become part of their intellectual landscape and do not warrant citation. Stephen Fleury, for instance, writes that

> Two philosophical principles characterize constructivism. . . . The first is that knowledge is actively built by a cognizing subject. . . . A second foundational principle . . . [is that] the function of cognition is to organize one'e experiential world, not to discover an ontological reality. (Fleury, 1998, pp. 157, 158)

Earlier, Grayson Wheatley offered a nearly identical summary of the epistemological core of constructivism, saying,

> The theory of constructivism rests on two main principles. . . . Principle one states that knowledge is not passively received, but is actively built up by the cognizing subject. . . . Principle two states that the function of cognition is adaptive and serves the organisation of the experiential world, not the discovery of ontological reality. . . . Thus we do not find truth but construct viable explanations of our experiences. (Wheatley, 1991, p. 10)

The late Rosalind Driver, in many publications, repeated elements of VGP. For instance,

> Although we may assume the existence of an external world we do not have direct access to it; science as public knowledge is not so much a discovery as a carefully checked construction. (Driver and Oldham, 1986, p. 109)

The intellectual core of von Glasersfeld's constructivism has been subject to detailed philosophical criticism by, among others Nola (1997), McCarthy and Sears (2000), McCarty and Schwandt (2000). There has been no more detailed and rigorous critique than that of Wallis Suchting, who concluded that

> First, much of the doctrine known as "constructivism" . . . is simply unintelligible. Second, to the extent that it is intelligible . . . it is simply confused. Third, there is a complete absence of any argument for whatever positions can be made out. . . . In general, far from being what it is claimed to be, namely, the New Age in philosophy of science, an even slightly perceptive ear can detect the familiar voice of a really quite primitive, traditional subjectivistic empiricism with some overtones of diverse provenance like Piaget and Kuhn. (Suchting, 1992, p. 247)

Unfortunately these critiques have been little attended to by constructivists. Von Glasersfeld in his 1995 book on radical constructivism fails to even mention Suchting's critique (Glasersfeld, 1995).

A FUNDAMENTAL PROBLEM: THE CONFUSION OF KNOWLEDGE AND BELIEF

For Piagetian personal constructivists, the paradigmatic case of knowledge is the individual confronting the world and making sense of their experiences: socialisation, enculturation, and language is pushed into the background. Alan Morf, for instance, in an article elaborating constructivist epistemology, wrote that "I consider knowledge as *experience-generated potentialities for action*" (Morf, 1998, p. 36), and he refers to an infant's first interactions with their environment as exemplary of this kind of knowledge. Anthony Lorsbach and Kenneth Tobin, in an article explaining the implications of constructivism for practising science teachers, wrote

> The constructivist epistemology asserts that the only tools available to a knower are the senses. It is only through seeing, hearing, touching, smelling, and tasting that an individual interacts with the environment. With these messages from the senses the individual builds a picture of the world. Therefore, constructivism asserts that knowledge resides in individuals. (Lorsbach and Tobin, 1992, p. 5)

For more social constructivists, their paradigmatic case of knowledge is individuals in a group discussing some phenomenon and coming to either common, or diverse, opinions on the matter. Thus Ann Howe and Harriet Stubbs, in a recent award-winning article advocating a constructivist account of knowledge development, ask what is the source of children's knowledge? They answer,

> Theory and practice in science education have emphasized experience with phenomena as they occur in nature or in the laboratory followed by reflection and discussion as the source. Having experienced the event or made the observation, the learner works through the cognitive dissonance that results and, in the process, constructs new knowledge. (Howe and Stubbs, 1997, p. 170)

In both cases there is a routine, but devastating, confusion of belief with knowledge: a psychological matter is confused with an epistemological one, and the consequence is educational havoc. Most of what constructivists maintain about knowledge is completely mistaken, but if "belief" is substituted for knowledge in their accounts, then a lot of the claims are perfectly sensible and some of them may even be right. Whether they are right or wrong is a matter of psychological investigation, that simply has nothing to do with epistemology or with deciding whether some claim constitutes knowledge. Children and adults have, since time immemorial, discussed matters with friends and have come to various beliefs about the natural and social world. This in itself has absolutely no bearing upon the truth of their beliefs, or on their claims to be knowledgeable. There was no end of discussion and agreement among Nazis about the subhuman status of the Slav peoples, likewise millions of Maoists during the Cultural Revolution came to believe that the educated class were counter-revolutionary running-dogs of capitalism, and millions of Hindus have for thousands of years believed that wives should accompany their deceased husbands into the next world. And of course, before Copernicus, there was no amount of agreement about the sun orbiting the earth. None of this mass agreement means anything for the truthfullness of the Nazi, Maoist, Hindu, or pre-Copernician claims.

The distinction between knowledge and belief is at least as old as Plato. In the justly famous *Meno* dialogue, the slave boy has been led to the true belief that the square on the hypotenuese is equal to the sum of the squares on the other two sides (and hence he is able to answer the initial query about how to double the area of a given square), however Plato asks whether his true belief constitutes knowledge.

He observes that

> At the present these opinions, being newly aroused, have a dream-like quality. But if the same questions are put to him on many occasions and in different ways, you can see that in the end he will a knowledge on the subject as accurate as anybody's. (Guthrie, 1956, p. 138)

What then is the difference between "dream-like" true opinions and "knowledgeable" true opinions? This is the standard teacher's and examiner's question. Later in the dialogue Plato answers the question in a way that has framed epistemological debate to the present time:

> True opinions are a fine thing and do all sorts of good so long as they stay in their place; but they will not stay long. They run away from a man's mind, so they are not worth much until you tether them by working out the reason. . . . Once they are tied down, they become knowledge, and are stable. That is why knowledge is something more valuable than right opinion. What distinguishes one from the other is the tether. (Guthrie, 1956, p. 154)

Plato holds a Reasoned True Belief account of knowledge that can be systemized as follows, where A stands for a cognizing subject and p for some proposition or statement of fact purportedly known by them:

"A knows p" $\equiv$ (i) p is true – Truth condition
(ii) A believes p – Belief condition
(iii) A has good reasons for believing p – Evidence condition

This view, in one form or another, has been epistemological orthodoxy since Plato's time. The central point is that belief, even true belief, is different from knowledge. This basic distinction is lost sight of in constructivist writing, where "children's ideas" and "children's knowledge" are regarded as synonymous; and where a belief being "viable" or "negotiated" warrants calling it knowledge.

AN EVIDENTIAL DILEMMA

Although constructivists appeal to realities about human learning and science, there is a problem because, for many constructivists, reality collapses into "my experience of reality." This is comparable, and not accidently so, to what happened to reality in the classic empiricism of Bekeley.[5] Antonio Bettencourt is just one of many constructivists who say, "...constructivism, like idealism, maintains that we are cognitively isolated from the nature of reality. . . . Our knowledge is, at best, a mapping of transformations allowed by that reality" (Bettencourt, 1992, p. 46).

Thus there is an "Evidential Dilemma" for constructivists: they wish to appeal to the nature of cognitive realities (learning processes) and epistemological realities (especially the history of science and mathematics) to support their pedagogical, curricular, and epistemological proposals. Thus one researcher who champions "sociotransformative constructivism" (STC), and who supports the position with a study of 18 students in a secondary science methods class, is impelled to remark that:

> Note that by using the term *empirical evidence*, I am not taking a realist or empiricist stance, nor any other Western orientation. I use the term "empirical evidence" with the understanding that knowledge is socially constructed and always partial. By "empirical evidence" I mean that information was systematically gathered and exposed to a variety of methodology checks. Hence in this study I do not pretend to capture the real world of the research participants (realism), nor do I pretend to capture their experiential world (empiricism). What I do attempt is to provide spaces where the participants' voices and subjectivities are represented along with my own voice and subjectivities. (Rodriguez, 1998, p. 618)

That constructivists suffer this "evidential dilemma" or "evidential discomfort" in not surprising. As a prominent constructivist in mathematics education has written:

> Put into simple terms, constructivism can be described as essentially a theory about the limits of human knowledge, a belief that all knowledge is necessarily a product of our own cognitive acts. We can have no direct or unmediated knowledge of any external or objective reality. We construct our understanding through our experiences, and the character of our experience is influenced profoundly by our cognitive lens. (Confrey, 1990, p. 108)

As lenses change, so seemingly does reality, and researchers with different lenses live in different worlds, and necessarily have to appeal to different "realities"

[5]See my discussion of the parallels between certain modern constructivisms and classical 17th century empiricism in Matthews (1992).

to support their claims. Just whose reality is the most real, or whose reality ought to drive education policy and funding, is left obscure. There are of course difficult interpretative problems regarding the relationship of evidence to theory, and good methodologists are aware of them and do their best to make the relationship more transparent, but constructivism creates an *in principle* barrier between evidence and theory. This then leaves legitimate methodological space for ideology, personal and group self-interest, or just "feel-goodness," to determine theory choice and acceptance.

THOMAS KUHN AND CONSTRUCTIVISM

Most leading constructivists acknowledge Kuhn as the fount of their relativist epistemology and their constructivist view of science. Derek Hodson wrote that "It has been argued earlier that Kuhnian models of science and scientific practice have a direct equivalent in psychology in the constructivist theories of learning. There is, therefore, a strong case for constructing curriculum along Kuhnian lines" (Hodson, 1988, p. 32). The opening sentences of a much cited paper by Ernst von Glasersfeld said that Kuhn's SSR "brought to the awareness of a wider public" the professional crisis "of faith in objective scientific knowledge" (Glasersfeld, 1989, p. 121). David Hawkins, in an article on the history of constructivism, wrote that *Structure* provided " 'constructivist' justification" for "philosophies of relativism and subjectivism" (Hawkins, 1994, p. 10). Joseph Novak acknowledged Kuhn as instrumental in the development of his own constructivist epistemology that underspins the children's alternative conceptions research programme (Novak, 1998, p. 6). Nancy Davis and colleagues used "Thomas Kuhn's (1970) work as a basis to support change in guiding epistemological paradigms" whereby they endorse constructivism and reject objectivism (Davis *et al.*, 1993, p. 627). The first sentence of Kenneth Tobin's anthology *The Practice of Constructivism in Science Education* rang with a Kuhnian allusion: "Currently there is a paradigm war raging in education" (Tobin, 1993, p. ix); and at least one contributor listed Kuhn's *Structure* as "one of the main constructivist sources of influence on my thinking" (Taylor, 1993, p. 268).

A clear danger with the wholesale endorsement of Kuhn's allegedly constructivist account of science, is that if the Kuhnian account is refuted, then one of the two linchpins of educational constructivism (the other being some version of Piagetian psychological constructivism) is removed.

Abner Shimony was charitable in saying of Kuhn's derivation of methodological lessons from scientific practice that "His work deserves censure on this point whatever the answer might turn out to be, just because it treats central problems of methodology elliptically, ambiguously, and without the attention to details that is essential for controlled analysis" (Shimony, 1976, p. 582). Less charitably, David Stove wrote this is "the reason why Kuhn can, and must, sentence all present and future philosophers of science to the torments of the damned: that is, to reading the sociology of science" (Stove, 1982, p. 19).

Kuhn does feed Stove's hellish vision. To recognise that ideas have a historical and social dimension, that concepts do not just drop out of the sky, and that people (including scientists) are products of their time—is all to the good (although the world did not have to await Kuhn to learn this). But to confuse these historical, psychological, and sociological matters with normative and logical ones is a major mistake. For Kuhn to describe *how* and *why* scientists fail to embrace new theories is an interesting enough historical and sociological lesson; for him then to claim that their recalcitrance and holding out was *justified* is an entirely different matter. The second is a *normative* judgement that depends (explicitly or implicitly) upon methodological criteria. Toulmin well advised on this point that

> Indeed, the more keenly one is aware of the interdependence of concepts and their contexts, the more indispensable certain distinctions become: for instance, that between the intrinsic authority of ideas and the magisterial authority of books, men and institutions, or that between the methodical acceptance of concepts whose merits have been demonstrated and the dogmatic acceptance of concepts whose merits are unproved. (Toulmin, 1972, p. 117)

Contrary to Kuhn there are aspects of methodology that are prior to, or independent of, the practice of science: logical rules, probability theory, and ethical norms, to start with (Shimony, 1976, pp. 582–586). These certainly do not constitute the full complement of methodological directives, and the balance needs to be teased out from engagement with, and reflection upon, the history and practice of science.

In 1993, when responding to commentators on his mature philosophical position, Kuhn reflected on

the reception of *Structure*, saying

> To my dismay, . . . my "purple passages" led many readers of *Structure* to suppose that I was attempting to undermine the cognitive authority of science rather than to suggest a different view of its nature. (Kuhn, 1993, p. 314)

Although he did not deny writing the "purple passages," he nevertheless lamented that scholars were missappropriating his work, saying that many were "retrieving from my work ideas that had no place there" (Hoyingen-Huene, 1993, p. xi). Philip Kitcher agreed with this assessment, saying earlier that much of what popularly passes for Kuhnian analysis is just a caricature of his views (Kitcher, 1982, p. 168). The physicist-philosopher, Abner Shimony, wrote of Kuhn's work that, "the great value of these insights has been debased by drawing from them relativistic and subjectivistic epistemological conclusions" (Shimony, 1991, p. 96).

Numerous educational constructivists have misunderstood Kuhn, and are guilty of drawing relativistic and subjectivistic epistemological conclusions from his work. There has been very little prolonged engagement with his writings, and even less prolonged critical engagement. As Loving and Cobern stated in their review of Kuhnian citations in science education, "None of the articles examined . . . offered any real critique of Kuhn's positions," and the science education community has become a "admiration society for Thomas Kuhn." (Loving and Cobern, 2000). This lack of sophistication about the history and philosophy of science is a major problem for the science education community, apart from other things it leaves the community prey to faddisms and intellectual snake-oil merchants.

CONSTRUCTIVIST TEACHING OF THE CONTENT OF SCIENCE

One response to criticism of constructivist theory is to say that constructivist pedagogy is valuable and should be encouraged, even if the theory is debatable. This position is understandable, but it rests on a moot point: namely, How efficacious is constructivist pedagogy in teaching science?

One prominent constructivist, Richard White, has said "although the research on alternative conceptions has sparked interest in content, it has not yielded clear advice about how to teach different topics" (Fensham *et al*., 1994, p. 255). Given the necessity for any science programme to teach the content of science is a serious failure.

The difficulty for constructivism posed by teaching the content of science is not just a practical one, it is a difficulty that exposes a fundamental *theoretical* problem for constructivism—if knowledge cannot be imparted, and if knowledge must be a matter of personal construction, then how can children come to knowledge of complex conceptual schemes that have taken the best minds hundreds of years to build up?

Many science educators are interested in finding out how, on constructivist principles, one teaches a body of scientific knowledge that is in large part abstract (depending on notions such as velocity, acceleration, force, gene), that is removed from experience (propositions about atomic structure, cellular processes, astronomic events), that has no connection with prior conceptions (ideas of viruses, antibodies, molten core, evolution, electromagnetic radiation), and that is alien to common-sense, and in conflict with everyday experience, expectations, and concepts? Teaching a body of knowledge involves not just teaching the concepts, but also the method, and something of the methodology or theory of method. How all of this is to be taught, without teachers actually conveying something to pupils, is a moot point.

Joan Solomon, a prominent British science educator, well articulates the problem:

> Constructivism has always skirted round the actual learning of an established body of knowledge . . . students will find that words are used in new and standardised ways: problems which were never even seen as being problems, are solved in a sense which needs to be learned and rehearsed. For a time all pupils may feel that they are on foreign land and no amount of recollection of their own remembered territory with shut eyes will help them to acclimatise. (Solomon, 1994, p. 16)

The constructivist research of the late Rosalind Driver and scholars at Leeds University illustrates the "skirting around" to which Solomon draws attention. In a recent book the Leeds group reasonably enough maintain that

> learning science involves being initiated into the culture of science. If learners are to be given access to the knowledge systems of science, the process of knowledge construction must go beyond personal empirical enquiry. Learners need to be given access not only to physical experiences but also to the concepts and models of conventional science. (Driver *et al*., 1994, p. 6)

There is near unanimity on this claim—conservatives and progressivists all agree, with perhaps just discovery-learners dissenting. The claim echoes the Leeds group's oft-repeated assertion that constructivism is different from discovery learning (Millar and Driver, 1987). But having made the above claim, the Leeds group go on to say that

> The challenge for teachers lies in helping learners to construct these models for themselves, to appreciate their domains of applicability and, within such domains, to use them.

One might reasonably ask whether, at this point, learning theory, or ideology, is simply getting in the way of good teaching. Why must learners construct for themselves the ideas of potential energy, mutation, linear inertia, photosynthesis, valency, and so on? Why not explain these ideas to students, and do it in such a way that they understand them? This process may or may not be didactic: it all depends on the classroom circumstance. There are many ways to explain science: didacticism is just one of them. Certainly a challenge for constructivist teachers lies in helping learners construct these ideas without violating constructivist learning principles. The Leeds group recognise this, and go on to say:

> If teaching is to lead pupils towards conventional science ideas, then the teacher's intervention is essential, both through providing appropriate experiential evidence and making the theoretical ideas and conventions available to pupils. (Driver *et al*. 1994, p. 6)

This is perhaps the precise point where Joan Solomon's "skirting around" is evidenced. How can a teacher make "the theoretical ideas and conventions available to pupils" without explaining them, without illustrating them, without showing their interconnections: in brief, without *teaching* them to pupils?

Constructivists addressed the problem of the teaching of the content of science at an international seminar held at Monash University in 1992. Its published proceedings were titled *The Content of Science: A Constructivist Approach to its Teaching and Learning* (Fensham *et al.*, 1994). Rosalind Driver and colleagues made a contribution to the seminar on "Planning and Teaching a Chemistry Topic from a Constructivist Perspective." They had children put nails in different places and observe the rate at which they rusted. They remarked that

> The theory that rusting is a chemical reaction between iron, oxygen and water, resulting in the formation of a new substance, is not one that students are likely to generate for themselves. (Scott *et al*., 1994, p. 206)

Indeed. After 10 pages describing how the teacher tries to "keep faith with students" reasoning . . . yet lead them to the intended learning goals" (p. 207), we are told that "The process of investigating personal ideas and theories may lead students to reflect upon and question them. At the same time, it is unlikely to lead to the scientific view" (p. 218).

Quite so. But where does this leave constructivism as a putatively useful theory for science teachers?

Most science teachers realize this difficulty. They try their best to explain things clearly, to make use of metaphors, to use demonstrations and practical work to flesh out abstractions, to utilise projects and discussions for involving students in the subject matter, and so on. They realize that many, if not most, things in science are beyond the experience of students and the capabilities of school laboratories to demonstrate. The cellular, molecular, and atomic realms are out of reach of school laboratories, as is most of the astronomical realm. It is fanciful to believe that sensory experience can, alone, be the foundation of a child's scientific knowledge. Most of the time even things that are within reach do not work. It is a rare school experiment that is successful. For children, a great deal of science has to be taken on faith. Good teachers do their best in the situation, and try to point out why faith in science is warranted. They may refer to texts or studies that have better controlled for experimental conditions than is possible in school settings. They may get students to appreciate the general directions in which school laboratory results are heading. They may do various other things to get pupils to see that their particular experience of a situation falls short of the experience that scientific investigation requires.

CONSTRUCTIVIST LANGUAGE: NEW REALITIES OR JUST NEW WORDS?

Constructivism has introduced some new words and meanings, it has borrowed terminology from progressive education traditions, and it has appropriated concepts from postmodernist sources. However it is not clear that new realities have been identified, or that old realities are better explained. Nor is it clear that long-standing problems of epistemology have been avoided, transcended or solved. Translations, such as the following, can easily be made from constructivist language to standard English and orthodox philosophy of science.

Constructivist new speak	Orthodox old speak
Perturbation	Anomaly
Viability	Confirmation
Construction of knowledge	Learning
Facilitating cognitive transformation	Teaching
Scheme	Theory
Conceptual ecology	Ideas
Accommodation	Theory change'
Negotiation of meaning	Student discussion
Dialogical interactive processes	Talking with each other
Student engagement	Paying attention
Off-task behavior	Not paying attention
Community of discourse	Group
Distinctive discoursive communities	Different groups
Personal construction of meaning	Understanding
Discourse	Writing
Verbal discourse	Speaking
Discoursive resources	Concepts
Habitus	Cultural environment
Symbolic violence	Learning something different
Mediational tools	Graphs
Conversational artifacts	Diagrams
Inscription devices	Drawings, diagrams, graphs
Cognitive apprenticeship	Education

Using such a translation manual, the following constructivist passages can be rewritten in simple everyday terms.

Constructivist speak	Plain speak
Since coparticipation involves the negotiation of a shared language, the focus is on sustaining a dynamic system in which discursive resources are evolving in a direction that is constrained by the values of the majority culture while demonstrating respect for the habitus of participants from minority cultues, all the time guarding against the debilitation of symbolic violence. (Tobin, 1998, p. 212)	Teach in a way that is sensitive to cultural values
. . . through our presence as facilitators and mentors, we can provide settings that are constrained and have minimal complexity so that students can construct conceptual and procedural knowledge with low risks of failure. (Roth, 1993, p. 168)	If students are taught simple things first, they are more likely to learn
[Constructivism] suggests a commonality amongst school science students and research scientists as they struggle to make sense of perturbations in their respective experiential realities. (Taylor, 1998, p. 1114)	Students and scientists consider adjusting their theories when confronted with anomalies
The discursive practices in science classrooms differ substantially from the practices of scientific argument and enquiry that take place within various communities of professional scientists. (Driver *et al.*, 1994, p. 9)	Student learning differs from scientific research
Making meaning is thus a dialogic process involving persons-in-conversation, and learning is seen as the process by which individuals are introduced to a culture by more skilled members. As this happens they "appropriate" the cultural tools through their involvement in the activities of this culture. (Driver *et al.*, 1994, p. 7)	Students need the assistance of teachers when learning new concepts
If students are to learn science as a form of discourse, then it is necessary for them to adapt their language resources as they practice science in settings in which those who know science assist them to learn by engaging activities of coparticipation occurs. (Tobin *et al.*, 1997, p. 493)	Students need new concepts and vocabularly in order to learn science
Our microanalytical view of the learning processes in one group showed how much the evolution of students" activities depended on features of the physical context, discourse contributions from individual group members, material actions on and with instructional artefacts, contingent interpretations, and the past history of the activity itself. (Duit *et al.*, 1998, p. 1070)	Our small study students showed that their learning is affected by peers and by the availability of educational resources

There is no in-principle problem with specialized vocabularies and theoretical terms: natural science is full of them. But whereas natural science uses theoretical terms to simplify complex matters, social science, at least in the above examples, is using theortical terms to make simple matters more complex.

There certainly are nonverbal differences between realists and serious constructivists. Realists believe that science aims to tell us about reality, not about our experiences; that its knowledge claims are evaluated by reference to the world, not by reference to personal, social, or national utility or viability; that scientific methodology is normative, and consequently distinctions can be made between good and bad science; that science is objective in the sense of being different from personal, inner experience; that science tries to identify and minimize the impact of noncognitive interests (political, religious, gender, class) in its development; that decision making in science has a central cognitive element and is not

reducible to mere sociological considerations; and so on.[6]

CONCLUSION

Constructivism has done a service to science and mathematics education: by alerting teachers to the function of prior learning and extant concepts in the process of learning new material, by stressing the importance of understanding as a goal of science instruction, by fostering pupil engagement in lessons, and other such progressive matters. But liberal educationalists can rightly say that these are pedagogical commonplaces, the recognition of which goes back at least to Socrates. It is clear that the best of constructivist pedagogy can be had without constructivist epistemology—Socrates, Montaigne, Locke, Mill, and Russell are just some who have conjoined engaging, constructivist-like, pedagogy with nonconstructivist epistemology.

Constructivism has also done a service by making educators aware of the human dimension of science: its fallibility, its connection to culture and interests, the place of convention in scientific theory, the historicity of concepts, the complex procedures of theory appraisal, and much else. But again realist philosophers can rightly maintain that constructivism does not have a monopoly on these insights. They can be found in the work of thinkers as diverse as Mach, Duhem, Bachelard, Popper, and Polanyi.

Given the influence of constructivism on education reform, teacher education, curriculum development and pedagogy, it is important to be clear about just what are, and are not, the epistemological commitments of constructivism. And what relationship these commitments have, if any, to classroom practice. One danger is that the good part of constructivist practice, the educational baby whose parentage is shared with the liberal education tradition, is in danger of being thrown out with the discredited epistemological bathwater—the "garage sale of outdated philosophical falsisms," as McCarty and Schwandt described constructivist philosophies (McCarty and Schwandt, 2000, p. 42). The history of education is littered with "ideas that seemed good at the time," but whose enactment caused educational and cultural havoc. Constructivism has all the earmarks of being such an idea. Perhaps when future historians of educational ideas look back on this period they might well agree with one commentator whose judgement was,

> In sum, constructivism is largely a reflection of current American cultural beliefs and, as such, involves the development of instructional techniques that attempt to make the acquisition of complex mathematical skills an enjoyable social enterprise that will be pursued on the basis of individual interest and choice. (Geary, 1995, p. 32)

[6]I have elaborated the core commitments of a "modest realism" in Matthews (1994, pp. 176–177).

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